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Nitrate Fluctuations in Ground Water as Influenced by Use of Fertilizer

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THE CONNECTICUT AGRICULTURAL EXPERIMENT STATION NEW HAVEN

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Fertilizers are often cited as sources of nitrogen in ground and surface water in suburban and rural areas. The most important nitrogen compounds found in soil solutions are ammonium (NH_4^+-N) and nitrate (NO_3^--N) nitrogen. NH_4^+-N is absorbed by the soil. However, NO_3^--N can be leached by heavy rain and eventually appear in ground and surface water. Nitrates at high concentrations in drinking water may be harmful to infants and livestock through impairment of oxygen transport in the blood. The U.S. Public Health Service limit for nitrate in drinking water for human consumption is $10\ mg\ L^{-1}$ (NO_3-N). The following investigations are an attempt to learn if fertilizers contribute to nitrate pollution of ground water in the Connecticut River Valley.

To study agricultural use of fertilizer I chose shade-grown wrapper-tobacco, which has been grown in the Connecticut River Valley for many years. It is heavily fertilized, mostly with natural nitrogenous organics, that in combination with cover cropping in time build high soil organic N levels. This study was made at the farm of the Valley Laboratory of The Connecticut Agricultural Experiment Station in Windsor and at a commercial shade tobacco farm in Suffield. To typify non-agricultural use of fertilizer I used turf plots at the Valley Laboratory farm. A network of sampling wells at the Valley Laboratory allowed sampling of the ground water flowing into, under, and out of the farm. A similar, but smaller, network of wells was installed at the commercial farm in Suffield.

EXPERIMENTAL CONDITIONS AND TREATMENTS

Both test sites are on nearly level to gently sloping terraces. The deep, well-drained, rapidly permeable soils at both locations are underlain by impervious glacial-lake deposits of silt and clay, over which perched ground water flows and fluctuates. These conditions allowed sampling of the ground water with relatively shallow wells.

Valley Laboratory Farm of The Connecticut Agricultural Experiment Station

This farm is about 1 mile west of the center of Windsor and generally drains in a southeasterly direction. The east side of the tillable area is bordered by wooded escarpments. Springs at the foot of these steep slopes feed a small brook that runs east into the Farmington River.

Soil conditions. As shown in Fig. 1, most of the cultivated area, about 4.5 ha (11 acres), consists of Merrimac sandy loam (Entic Haplorthod), a moderately coarse-textured soil developed over coarse sand and gravel, which occur at a depth of about 60 cm (2 ft). It is very friable, rapidly permeable, and has a moderate moisture-holding capacity (22).

Next in importance is an area of Merrimac fine sandy loam, which is moderately to rapidly permeable and has a moderate to high moisture-holding capacity. The slightly higher ground upon which the tobacco

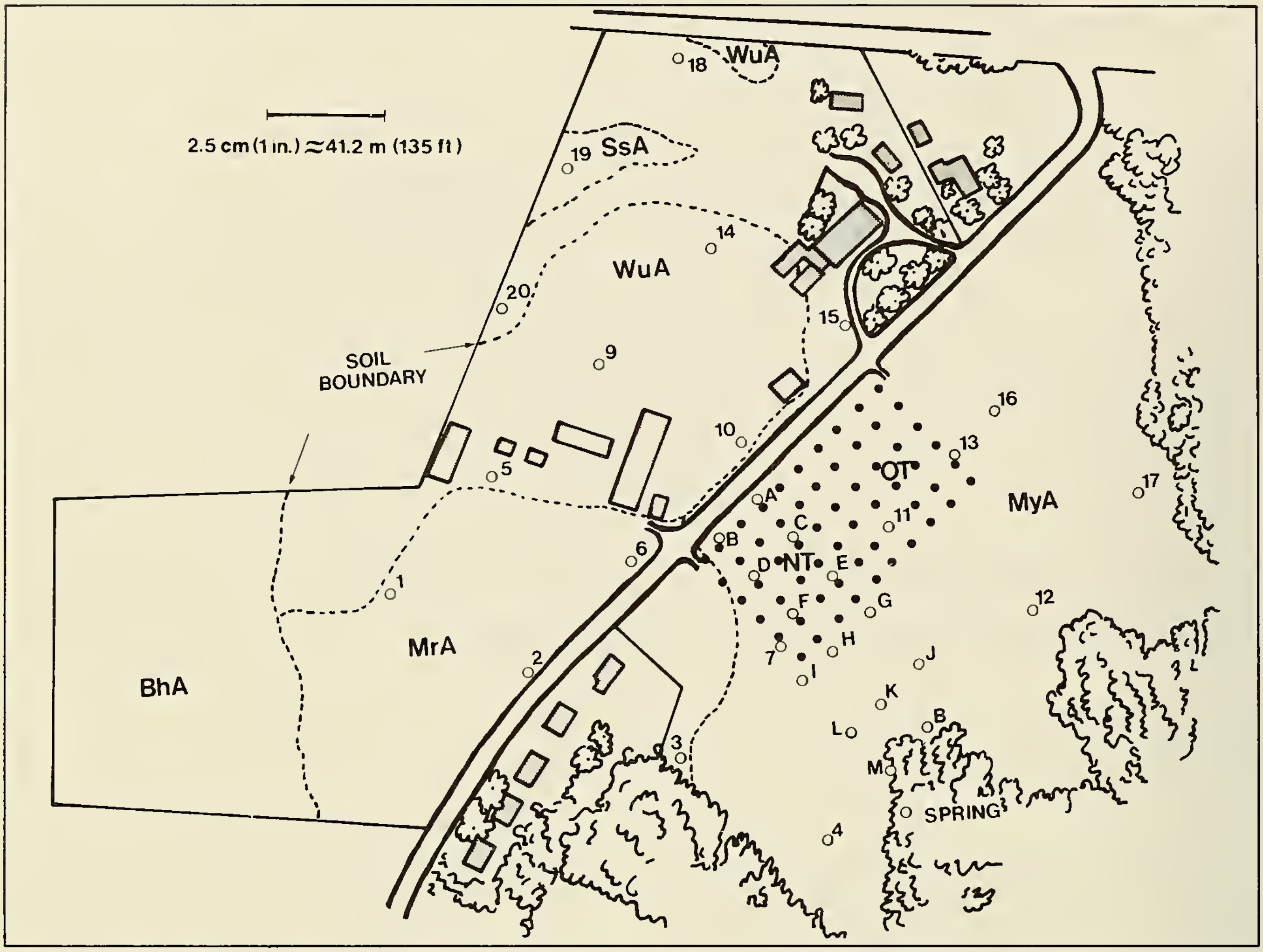

Fig. 1. Map of the Valley Laboratory Farm at Windsor, prepared from an aerial photograph (1955). Buildings are shaded. OT: old shade tent; NT: new shade tent. Soils: MyA = Merrimac sandy loam, 0-3% slopes; MrA = Merrimac fine sandy loam; WuA = Windsor loamy coarse sand; SsA = Sudbury fine sandy loam; BhA = Birchwood fine sandy loam; unfilled circles 1-20 = main network of wells; unfilled circles A-M = wells covering new shade tent area; filled circles = poles of old and new shade tents.

barns, toolshed, and workshop are situated is classified as Windsor loamy coarse sand, a droughty soil associated with the Merrimac soils. Another soil closely associated with Merrimac, Sudbury fine sandy loam, a moderately well-drained soil with a seasonably high water table, takes up a small strip in the north-west corner of the area covered by the grid of sampling wells. In most of this grid-area the varved silt and clay layers are found at a depth of about 2.40-3.60 m (8-12 ft), while the water table fluctuates between 1.80-2.70 m (6-9 ft).

Treatments and location of sampling wells.

Experimental farm. Except for small areas of experimental tobacco and turf plots, the farm is not intensively cultivated or fertilized. About 0.8 ha (2 acres) are planted with ornamental liners and shrubs used in herbicide tests. Fertilization is light because nursery stock needs relatively low amounts of fertilizer, sometimes applied on a per plant basis. Two grades of fertilizer were used: 10N-4.4P-8.3K (10N-10P_2O_5-10K_2O) and 10N-2.6P-2.5K (10N-6P_2O_5-4K_2O). The highest rate at which fertilizers are used was about 900 kg/ha (800 lbs/acre). About 1.4 ha (3.5 acres) were cover-cropped without fertilization. I estimate that 90 kg/ha or 280 lbs of N were applied annually.

A network of 13 wells consisting of rigid plastic tubes reaching down to the clay substratum was installed during Spring 1975. The main spacing of the wells was 61 x 62 m (200 x 202.5 ft). The first series of ground water samplings took place on May 21, 1975. In June 1976, the network was expanded to 20 wells.

Old shade tobacco area (Fig. 1-OT). From 1968-1976, the area around well No. 11 and next to well 13 was used for shade-grown cigar-wrapper tobacco (*Nicotiana tabacum* L.). The shade tent (Fig. 1-OT), consisted of 4 x 5 = 20 bents = 0.55 acre or about 0.2 ha. A bent is the area between the posts, which are set in a square grid of 10 m (33 ft) to support the wires over which the tent cloth is stretched.

Conventional fertilizer formulas for cigar tobacco (1,5) were generally used. The main nitrogenous material is cottonseed meal, supplemented with other

natural organics, such as soybean, linseed, and fishmeal. These materials provide about 196 kg/ha (175 lbs/acre) of N, supplemented with 22 to 34 kg/ha (20-30 lbs/acre) NO_3-N. Precipitated bone, triple superphosphate, cottonhull ashes, or potassium sulfate is added to increase the P and K levels to around 66 kg/ha P_2O_5 (60 lbs/acre) and 166 kg/ha K_2O (150 lbs/acre).

Ground water flows roughly from north-west to south-east (Fig. 1 & 3) through the tent area towards well 11, which was therefore favorably located for representative sampling. Well 13 was 2.75 m (9 ft) outside the north-east side of the shade tent.

In Spring 1977 this shade tent was replaced by a new tent of the same size, set up in the adjacent west corner of the same field (Fig. 1-NT).

New shade tobacco area (Fig. 1-NT). This area had been used for a buckwheat cover crop without fertilization in 1976. Part had been used previously for experiments with potatoes. This 20-bent area tent was planted to shade tobacco and managed according to standard practices (1,5). Here, the fertilization provided 227 kg/ha N (203 lbs/acre) with 220 kg/ha P_2O_5 (196 lbs/acre), and 282 kg/ha K_2O (252 lbs/acre).

A few days before the fertilizer was worked in on May 26, 1977, a compact network of 13 wells (A-M), was installed in and outside the tent (Fig. 1-NT). Wells A and B were about 1.83 m (6 ft) west or upstream of the tent and wells G-M downstream. To supplement the up- and downstream ground water sampling of this new shade tent area we added respectively, well 6 and 10, and well 4 and 7 of the old network. The ground water sampling began June 13, 1977.

Turf plots. The turf plots were established in August 1975 in an area used previously for infiltration studies (23). The four plots 4.6 x 6.1 m (15 x 20 ft) were limed, tilled, fertilized, and seeded with a standard turfgrass mixture, as recommended by The Cooperative

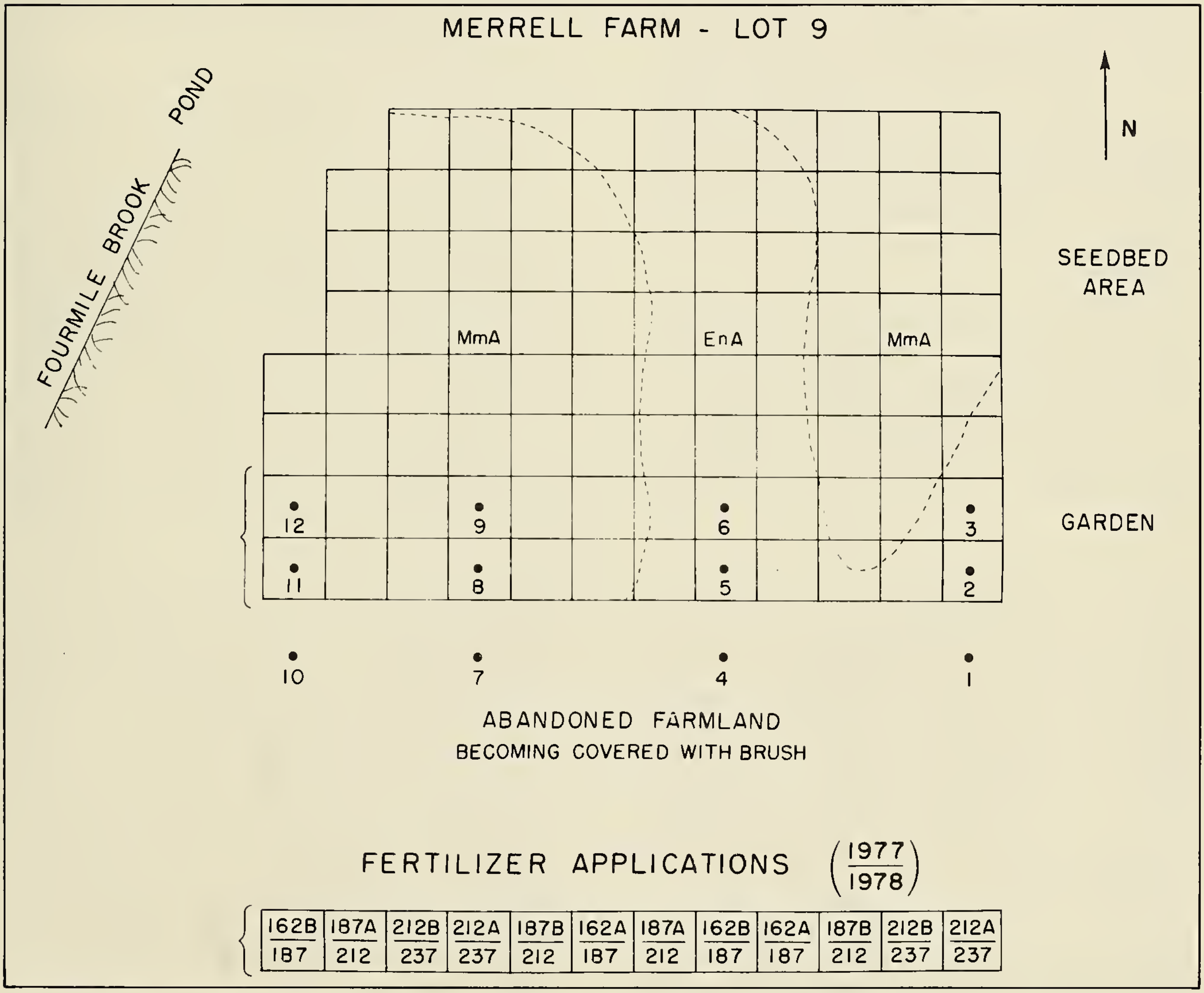

Fig. 2. The layout of field 9 of the Merrell Farm, Suffield, with the various fertilizer treatments in 1977 and 1978 and the location of wells no. 1 to 12 and the irrigation pond, (sampling point no. 13). Soils: MmA = Melrose sandy loam, 0 to 3% slopes; EnA = Elmwood sandy loam; filled circles = wells.

Table 1. Nitrogen fertilizations of shade tobacco at various pre- and post-planting amounts and applications in kg/ha (lbs/acre) — Merrell Farm, Suffield, CT.

Fertilization code		Total nitrogen		Dehydrated manure		Preplant fertilizer		Postplant fertilizer					
								Day 8		Day 16		Day 24	
1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978
162A	187A	181 (162)	209 (187)	34 (30)	34 (30)	76 (68)	120 (107)			45 (40)	56 (50)	28 (25)	
162B	187B	181 (162)	209 (187)	34 (30)	34 (30)	48 (43)	75 (67)	28 (25)	22 (20)	45 (40)	56 (50)	28 (25)	22 (20)
187A	212A	209 (187)	237 (212)	34 (30)	34 (30)	103 (92)	148 (132)			45 (40)	56 (50)	28 (25)	
187B	212B	209 (187)	237 (212)	34 (30)	34 (30)	76 (68)	103 (92)	28 (25)	22 (20)	45 (40)	56 (50)	28 (25)	22 (20)
212A	237A	237 (212)	265 (237)	34 (30)	34 (30)	159 (142)	176 (157)			45 (40)	56 (50)		
212B	237B	237 (212)	265 (237)	34 (30)	34 (30)	103 (92)	131 (117)	28 (25)	22 (20)	45 (40)	56 (50)	28 (25)	22 (20)

Extension Service (19). We applied 0.49 kg N/100 m^2 (1 lb N/1000 ft^2) of 10N-2.6P-3.3K (10N-6P_2O_5-4K_2O), before seeding followed by 0.24 kg N/100 m^2 (½ lb N/1000 ft^2) 14 days later. After the turf was established, it was fertilized at the rate of 1.95 kg N/100 m^2 (4 lbs N/1000 ft^2) annually. Half was applied in April-May, the other half in September-October. A standard 10N-2.6P-3.3K (10N-6P_2O_5-4K_2O) grade lawn-fertilizer was used, containing water-soluble and water-insoluble N. The slowly available N, which makes up 50% of the total, is mainly derived from urea-formaldehyde.

The grass was cut as required, once a week in spring and fall and once every 2 weeks in summer. The clippings were harvested, weighed, and subsampled for analysis of total N. The grass clippings were returned to two plots and removed from the other two.

Samplings from well 1 and 5 characterized the NO_3 background levels. These wells were west of the turf plots, i.e., upstream of the general water flow into the turf plots.

Merrell Farm, Suffield

This farm has been in intensive tobacco production for decades. It offered an opportunity to study the long-term effects of tobacco fertilization and management practices on the NO_3-N concentrations in ground water. It has been cultivated for shade-grown wrapper tobacco since 1951. Prior to 1951, non-shade broadleaf tobacco was grown (1). Fertilization is similar to that for shade tobacco, using the same or similar organic materials. A standard grade, 6N-1.3P-5K (6N-3P_2O_5-6K_2O) is usually applied at a rate of 3000-4000 kg/ha (2700-3600 lbs/acre) (5).

In 1977, we selected a relatively small field (No. 9) of 91 bents (0.9 ha = 2.3 acres, see Fig. 2) for the tests. Its location in the south-east corner of the cultivated area served our study well. Field 9 is bordered on the east by lightly cultivated land, and by fallowed land, which is becoming covered by brush, to the south. This land drains into Fourmile Brook, which runs along the west and north-west side of the field. This field had been covercropped in 1972 and 1973 to sustain good yields of high quality tobacco.

Soil conditions. The soils of field 9 have developed from glaciolacustrine, glaciofluvial, or windblown deposits underlain by glacial-lake deposits of silt and clay at a depth of 76-122 cm (2.5-4 ft). Most of the field consists of Melrose sandy loam (MmA), which is rapidly permeable and with a moderate moisture-holding capacity above the silt and clay strata. The internal drainage is not as free as that in the Merrimac sandy loam. A closely associated soil, Elmwood sandy loam (EnA), takes a small area in the south-east corner and a strip running south to north through the middle of the field. In this moderately well-drained soil, the silt and clay subsoil may be found at depths of 61-122 cm (2-4 ft) (22).

Treatments and location of sampling wells. The experimental area is made up of two rows of 12 bents, running west to east along the south edge of Lot 9. The six fertilization treatments, each applied on 2 bents (200 m^2 = 2178 ft^2), were randomized in two replicates (Fig. 2).

The treatments consisted of three levels of N, each applied on the basis of two programs, A and B, of preplant and postplant fertilizations (Table 1). The standard fertilization of this farm (treatment 212A) is 237 kg/ha (212 lbs N/acre) split in a preplant fertilization of 193 kg N/ha (172 lbs N/acre), which includes 34 kg/ha (30 lbs/acre) of N in the form of dehydrated manure, followed 16 days after planting with 45 kg N/ha (40 lbs N/acre). The differential treatments were made by decreasing the preplanting fertilization and the splitting of the usual postplanting fertilization on day 16 into three, applied on day 8, 16, and 24. These changes were programmed to diminish the risk of leaching of NO_3 and to supply the plants with N throughout the growing season.

The nitrogenous ingredients used in the preplanting tobacco fertilizer mix were cottonseed, soybean, linseed and castor pomace meal, respectively providing in the standard application 212A: 75 (65), 40 (36),

20(18), and 18.5 (16.5) kg/ha (lbs/acre) of nitrogen. This application also contained NO_3-N in the form of potassium nitrate (7.3 kg/ha or 6.5 lbs/acre). The standard postplanting fertilization, however, applied three times as much NO_3-N, as potassium nitrate (11 kg/ha or 10 lbs/acre) and calcium nitrate (9 kg/ha or 8 lbs/acre). The latter ingredients were mixed with cottonseed meal (25 kg/ha or 22.5 lbs/acre of N).

The field and the experimental plots were fertilized on May 17, 1977. Tobacco transplants were planted 7 days later.

The wells to sample the ground water beneath the various fertilizer treatments were limited to treatment 162B and 212A in each replicate (Fig. 2). This selection covers the extremes of the fertilization rates. Besides being the lowest total application of fertilizer, treatment 162B represents the timing least likely to cause potential NO_3 leaching. Treatment 212A, on the other hand, represents the highest and most concentrated application of fertilizer most prone to leaching losses of NO_3. One well was placed in the middle of each bent of these two treatments, while a third well was located to the south about 10 m (33 ft) outside the tent at the edge of abandoned farm land overgrown with weeds, a few shrubs and small trees.

TECHNIQUES

The wells, made of 3.66 m (12 ft) rigid plastic tubes (ID 4.0 cm = 1½ inch), were pushed through vertical holes, punched to the ground water level with aluminum tubing (OD 4.1 cm = 1⅝ inch). The wells were lowered further with the help of a jet of water from a 2.5 cm (1 inch) plastic pipe connected to a hose. The wells were inserted into the soil profiles to a depth of 2.40 to 3.30 m (8-11 ft), i.e., until silt and/or clay particles were washed up. The holes in the lower 2.1 m (7 ft) of the wells have a diameter of 4.8 mm (3/16 inch) and are not covered with a screen. They are drilled in alternating directions across the plastic tubes, 15 cm (6 inches) apart.

After the wells were installed, we measured their elevations with a surveyor's transit. The ground water depth was measured with an electric waterlevel probe (8) prior to sampling. Samples were taken every 2-4 weeks, depending on weather conditions and experimental requirements by lowering a small cup (10 cc = 1/3 fluid ounce), attached to a thin cord. Two samples were taken; the first to rinse the cup, the second for NO_3^--N analysis.

We made several samplings to test our technique. Nylon tubing (1 mm I.D.) and a small suction pump were used to take samples from the top 10-cm (4 inches) layer, the bottom 10-cm (4 inches) layer and sometimes halfway between these two levels in the usually 30-cm (1 ft) deep to 60-cm (2 ft) deep perched water table. The insignificant differences in NO_3-N concentration at these levels justified sampling from the top 10-15 cm (4-6 inches). No significant differences in NO_3-N concentration were found between the water standing in the well or water that filled the well after it was emptied. Both observations indicate that the coarse-textured deeper soil layers above the silt and clay strata allow sufficient water flow and diffusion of its solutes.

The ground water under the turf plots was sampled with porous ceramic suction cups (5). In each plot two sets of two probes each were installed below the water level, to a depth of 240 cm (8 ft), and 300 cm (10 ft).

The ground water samples were analysed for NO_3-N after collection by the chromotropic acid method (7). They were refrigerated at 2°C (36°F) if storage was necessary.

RESULTS

Valley Laboratory

Experimental farm. Observations clearly established the ground water divide to the west and in the north-west part of the farm and the main drainage to the south-east and east. Fig. 3 illustrates the general directions of flow. The small area with the moderately well-drained Sudbury fine sandy loam in the north-western part of the farm (Fig. 1) appears to drain in a north-westerly direction.

During May 1975 to May 1978 the difference in water table elevations between the wells along the western side of the farm and the eastern fringe of the

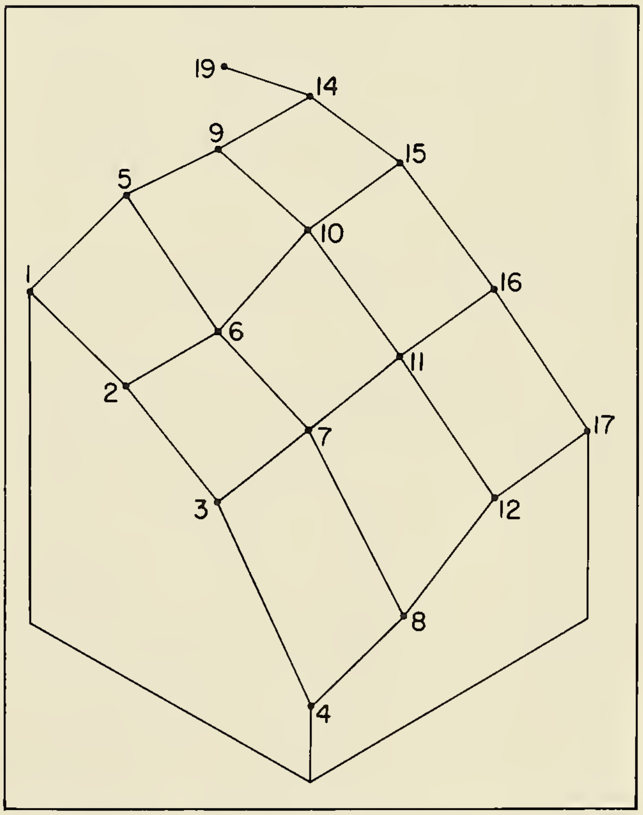

Fig. 3. Relative ground water elevations as measured in main network of wells on the Valley Laboratory farm at Windsor (See Fig. 1). Averages of 3 years of observations, May 1975-78.

Table 2. Summary of NO_3-N concentrations (mg L^{-1}) in the ground water under the farm of the Valley Laboratory at Windsor.

Season	Sampling dates	Incoming[z]	Under-W	Under-E	Outgoing
Summer	June 3-Aug. 27, 1975	0.7 ± 0.6[y]	3.2 ± 3.0	1.9 ± 1.2	2.4 ± 2.4
Fall	Sept. 30-Nov. 26, 1975	2.7 ± 2.0	3.8 ± 1.2	2.3 ± 1.8	6.1 ± 4.9
Winter	Jan. 14-March 23, 1976	1.9 ± 1.2	2.8 ± 1.6	2.4 ± 1.3	4.6 ± 2.3
Spring	Apr. 21-June 22, 1976	1.8 ± 1.0	2.6 ± 1.6	2.0 ± 1.3	4.0 ± 1.2
Summer	July 14-Sept. 13, 1976	3.2 ± 1.9	2.5 ± 1.3	2.5 ± 1.3	3.6 ± 1.1
Fall	Sept. 28-Nov. 30, 1976	3.5 ± 1.7	3.3 ± 0.6	3.4 ± 2.0	3.9 ± 1.2
Winter	Dec. 22-March 9, 1977	3.7 ± 2.0	4.4 ± 1.9	3.7 ± 2.6	3.0 ± 1.4
Spring	Apr. 1-June 21, 1977	2.5 ± 2.4	1.8 ± 1.0	2.0 ± 1.0	3.3 ± 3.9
Summer	July 14-Sept. 13, 1977	2.1 ± 1.4	3.0 ± 1.7	2.7 ± 1.2	3.9 ± 2.0
Fall	Sept. 27-Dec. 15, 1977	4.2 ± 4.0	4.3 ± 2.0	3.0 ± 1.1	4.2 ± 2.7
Winter	Feb. 16-March 9, 1978	1.7 ± 1.4	3.1 ± 2.0	2.5 ± 0.9	5.6 ± 3.2
Spring	Apr. 13-May 26, 1978	1.6 ± 1.0	2.0 ± 1.5	1.6 ± 0.6	3.2 ± 1.7
Summer 1975-Spring 1978		2.5[x]	3.1	2.5	4.0[x]

[z]Incoming: Wells 1, 5, 9, 20, 19, 18 — Sampling ground water just entering the farm.

Under-West: Wells 2, 6, 10, 15, 14 — Sampling ground water under the farm west of Cook Hill Road.

Under-East: Wells 3, 7, 11, 13, 16 — Sampling ground water under the farm, east of Cook Hill Road.

Outgoing: Wells 4, 8, 12, 17, Spring — Sampling ground water leaving the farm.

[y]NO_3-N in mg L^{-1} ± Standard error of the mean.

[x]The t-test showed the difference between incoming and outgoing means to be significant at the 0.01 level.

cultivated area averaged about 66 cm (2.2 ft). Periods of heavy rainfall, rapidly recharging the ground water, took place during September 23-27, 1975 (196 mm = 7.72 inch) and October 11-20, 1975 (126 mm = 4.97 inch), March 4-22, 1977 (150 mm = 5.89 inch), and September 16-26 (194 mm = 7.63 inch). The fluctuation between the highest (October 1975) and the lowest water table levels (February 1977) in the upstream area of the ground water flow under the farm (well 9) amounted to 105 cm (3.3 ft); in the downstream area (well 4) the fluctuation was 78 cm (2.6 ft).

The NO_3-N concentrations during the 3 years are summarized in Table 2. For analysis, the wells were considered relative to the ground water flow. The wells along the western border of the farm represented ground water entering the farm. Wells sampling the water under the mid-section of the farm were west and east of the street. Finally, the wells and spring along the eastern edge of the farm sampled ground water about to leave the farm (see further Table 2 and Fig. 1). The data from these wells are further grouped to cover four seasons.

Table 2 shows that the NO_3-N concentrations under the Valley Laboratory farm are relatively low and are variable within the groups of wells. The differences between the incoming, west and east wells are minor and inconsistent. In the outgoing wells, however, a slight, but highly significant ($t > .01$) increase in NO_3 concentrations was observed. The source of these nitrates is difficult to find. The use of fertilizer on this farm, as mentioned before, is generally light and high rates are mainly concentrated on a 0.2 ha (0.5 acre) field growing shade tobacco and four small turf plots. Several fields, however, were plowed, disked and seeded with cover crops. Although no fertilizer was used on these crops, such cultivation affects organic matter mineralization and contributes to NO_3 accumulation in ground water (25).

During the 3 years of monitoring, NO_3-N exceeded 10 mg L^{-1} eight times. The maximum was 19 mg L^{-1}. These relatively high NO_3 concentrations usually occurred during or after periods of heavy rains in the fall or winter. Most of these temporary increases were measured in the "outgoing" wells located downstream of the heavily fertilized shade tent area. The "incoming" well 18 and "nearby" wells 19 and 14 (Fig. 1), showed a single sudden increase to 18 mg L^{-1} NO_3-N during heavy rain in September 1977 (194 mm = 7.63 inch). As these wells are near a residential area, this suggests an outside, domestic source of contamination.

Old shade tobacco area. For the last 9 years the old shade tent area (Fig. 1-OT) was used mostly for shade tobacco experiments and had been fertilized heavily as compared to the rest of the Valley Laboratory farm.

Table 3 summarizes the observations on ground water. Only one well, No. 11, was within the test area, although well No. 13 was just outside the northeastern border.

Again the NO_3-N concentrations shown in Table 3 are generally low, particularly those observed in the upstream area and in wells 11 and 13. In the downstream wells (8 and 12), however, an overall, small increase in NO_3-N concentration was observed; on at least four occasions concentrations of over 10 mg L^{-1} were observed. Fig. 4 shows a situation that occurred in the Fall, 1975. Wells 8 and 12 showed high NO_3 concentrations and, as they were downstream of the old shade tent, it was reasonable to assume that these nitrates came from the tent area as a result of

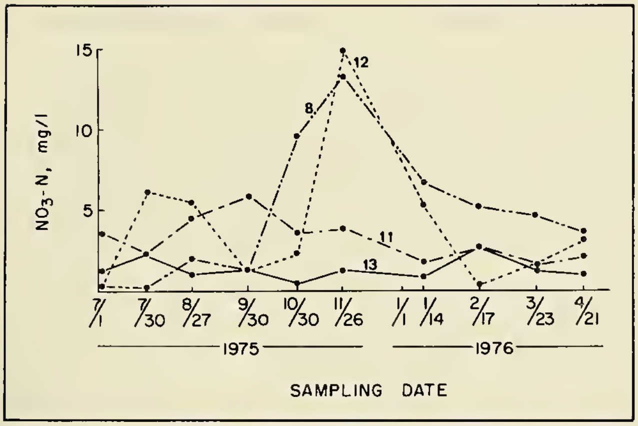

Fig. 4. Changing NO_3-N concentrations in 4 wells on several sampling dates on the Valley Laboratory farm, Windsor.

196 mm (7.72 inch) of rain in late September. Well 11, although located in the southeastern corner of the shade tent area, showed only a slight increase in NO_3 during this period. This is understandable because vertical movement of water and its solutes in layered soils, such as this Merrimac sandy loam, occurs most readily along certain pathways or fingers (23). Under such conditions, observations at a single well do not offer a true picture of the NO_3 percolation. Also, channels of more permeable material on top of the clay layer may provide horizontal pathways by which pollutants move and cause temporary high NO_3 concentrations in certain wells, such as at wells 8 and 12. At the same time, well 13 did not show an increase in NO_3 (Fig. 4), probably because it is on the upstream side of the ground water flow. However, during the winter of 1976-77, well 13 showed a sudden increase in NO_3 concentration, again characteristic of these shortlived, local NO_3 accumulations in the ground water.

During 1977 and Winter 1977-78, high NO_3-N concentrations occurred more often in the downstream wells, raising the average concentrations to relatively high levels of 5 to 8 mg L^{-1} (Table 3). It appears that the heavy rainfall in spring, fall, and winter was the main factor in producing these NO_3 fluxes. Although the shade tobacco had been moved to a new area after the 1976 season, the residual soil fertility from 9 years of shade growing must have been the main source of NO_3, particularly in the spring. However, later in the 1977 season some of the nitrates could have come from half of the tent area (10 bents = 0.28 ha = 0.25 acres) that was planted to field corn, fertilized at the rate of 165 kg of inorganic N/ha (150 lbs/acre).

New shade tobacco area. The one year's observations in the wells in and around the new shade tent area are tabulated in Table 4. The average NO_3-N concentrations are slightly higher than those observed for the farm (Table 2) and similar to the ones found for the old shade tent area. Nitrate-N concentrations over 10 mg L^{-1} were only found in the downstream well J during three samplings between August 2 and September 15, 1977. Part of the NO_3 enrichment may have come from the old shade tent area, since it is located almost directly upstream of well J (See Fig. 3 and 1). Under the new shade tent area the same effect is noticeable. Wells C and E, located nearest to and downstream of the old shade tent, show generally higher NO_3-N concentrations than wells D and F.

This new shade area, with its many wells, will be used to study the cumulative effect of a relatively high, organic, nitrogenous fertilization on the NO_3 enrichment of the ground water.

Table 3. Summary of NO_3-N concentrations (mg L^{-1}) in the ground water upstream, under and downstream of the old shade tobacco area on the Valley Laboratory, Windsor.

		Upstream[z]		Under				Downstream	
				Well 11		Well 13			
Season	Sampling dates	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
Summer	June 3-Aug. 27, 1975	1.2	0.4-2.6	2.9	1.0-4.6	1.3	0.6- 2.3	3.0	0.3- 6.9
Fall	Sept. 30-Nov. 26, 1975	4.0	3.4-4.2	4.5	3.6-5.9	1.0	0.3- 1.4	7.0	1.2-15.0
Winter	Jan. 14-Mar. 23, 1976	3.5	3.4-3.6	2.0	1.6-2.6	1.7	1.0- 2.7	4.0	0.4- 6.8
Spring	Apr. 21-June 22, 1976	3.3	3.1-3.5	3.5	2.2-4.7	1.8	1.1- 2.8	4.0	3.2- 6.4
Summer	July 14-Sept. 13, 1976	2.2	0.9-3.2	2.9	1.6-5.7	3.8	2.2- 5.8	3.9	0.8- 5.6
Fall	Sept. 28-Nov. 30, 1976	3.5	2.4-4.1	3.8	3.0-5.5	6.8	5.5- 7.2	4.6	3.2- 7.2
Winter	Dec. 22-March 9, 1977	3.5	1.2-4.2	3.8	2.5-5.0	8.1	6.2-11.5	3.2	0.8- 5.0
Spring	Apr. 1-June 21, 1977	2.4	1.2-2.8	2.3	1.9-2.9	4.4	1.2- 3.0	5.1	0.6-19.2
Summer	July 14-Sept. 13, 1977	3.5	1.4-6.8	1.6	1.4-1.9	3.9	2.4- 5.0	5.7	3.0- 8.5
Fall	Sept. 27-Dec. 15, 1977	4.2	3.0-5.2	2.8	1.8-3.4	2.8	1.6- 5.2	6.8	4.6-10.4
Winter	Feb. 16-March 9, 1978	4.2	3.6-4.8	2.4	2.3-2.4	1.4	1.3- 1.4	8.3	6.0-14.0
Spring	Apr. 13-May 26, 1978	3.6	1.8-4.4	2.2	1.9-2.5	0.7	0.2- 1.2	3.6	2.2- 4.8
Summer 1975 -Spring 1978		3.2	0.4-6.8	2.9	1.0-5.9	3.1	0.2-11.5	4.9	0.3-19.2

[z]Upstream: Wells 10 and 15 combined

Under: Well 11 located in S corner of shade tobacco area (Fig. 1)
Well 13 located on NE border of shade tobacco area (Fig. 1)

Downstream: Wells 8 and 12 combined

Table 4. Summary of NO_3-N concentrations (mg L^{-1}) in the ground water upstream, under, and downstream of the new shade tobacco area at the Valley Laboratory Farm, Windsor.

Season	Sampling dates	Upstream[z] Avg.	Upstream[z] Range	Under Wells C & E Avg.	Under Wells C & E Range	Under Wells D & F Avg.	Under Wells D & F Range	Downstream Avg.	Downstream Range
Spring	May 26-June 27, 1977	2.5	1.0-4.2	3.3	2.8-3.9	3.4	2.2-4.4	3.8	2.3- 6.0
Summer	July 14-Sept. 27, 1977	3.6	1.1-9.4	4.5	3.1-5.8	2.4	1.0-4.0	5.5	3.0-13.8
Fall	Oct. 18-Dec. 15, 1977	4.4	1.8-8.6	6.9	5.8-7.9	4.0	2.4-6.1	5.6	1.4- 8.9
Winter	Dec. 23-March 9, 1978	4.5	1.8-7.1	5.1	3.6-7.4	5.2	3.7-6.8	6.3	0.4- 8.6
Spring	March 14-June 16, 1978	2.8	0.5-4.4	5.7	4.6-8.2	3.9	2.4-4.8	4.8	1.4- 7.4
Spring 1977 -Spring 1978		3.6	0.5-9.4	5.1	2.8-8.2	3.8	1.0-6.8	5.2	0.4-13.8

[z]Upstream: Wells 10, 6, A, and B combined

Under: Wells C, E, located in shade tent, about 20 m (66 ft) SSW of the old shade tobacco area.

Wells D, F, located in shade tent, about 10 m (33 ft) NNE of a fallowed field.

Downstream: Wells G, H, I, J, K, and L combined.

Table 5. Summary of NO_3-N concentrations (mg L^{-1}) in the ground water upstream of and under turf plots at the Valley Laboratory Farm, Windsor.

Season	Sampling dates	Upstream wells: Well 1 Avg.	Well 1 Range	Well 5 Avg.	Well 5 Range	Turf Plot Wells: Clippings Returned Avg.	Clippings Returned Range	Clippings Removed Avg.	Clippings Removed Range
Summer	Aug. 21-Sept. 29, 1975	1.4	0.2-2.6	2.1	1.8-2.4	2.9	0.8- 8.0	2.9	1.0-6.7
Fall	Oct. 14-Dec. 2, 1975	0.5	0.4-0.6	1.3	0.9-1.7	2.6	0.4-10.0	1.4	0.6-4.6
Spring	March 30-June 18, 1976	0.6	0.5-0.6	2.2	1.8-2.5	1.1	0.3- 3.8	1.1	0.3-2.2
Summer	July 2-Sept. 20, 1976	0.9	0.7-1.0	5.1	3.7-6.8	1.4	0.4- 4.0	1.5	0.6-2.9
Fall	Sept. 28-Dec. 21, 1976	1.2	0.6-1.6	2.8	1.7-5.5	1.8	0.5- 3.6	1.6	0.8-5.6
Spring	May 13-June 27, 1977	0.7	0.2-1.2	3.0	2.7-3.4	1.5	0.3- 3.2	1.7	0.7-2.8
Summer	June 30-Aug. 18, 1977	0.7	0.6-0.8	2.6	2.4-2.8	2.0	0.6- 4.5	2.2	1.2-4.5
Fall	Sept. 21-Dec. 23, 1977	1.2	0.8-1.6	2.2	1.6-2.8	2.8	0.9- 5.1	2.5	1.0-5.6
Spring	Apr. 25-June 5, 1978	0.7	0.4-1.0	1.9	1.8-2.0	2.0	0.8- 4.8	1.8	0.8-3.2
Summer, 1975 -Fall, 1977		0.9	0.2-2.6	2.7	0.9-6.8	2.0	0.3-10.0	1.9	0.3-5.6

Table 6. Summary of NO_3-N concentrations (mg L^{-1}) in the ground water near and under a commercial shade tobacco field, Merrell Farm, Suffield.

Well No.	Season 1977-1978: Summer Avg.	Summer Range	Fall Avg.	Fall Range	Winter Avg.	Winter Range	Spring Avg.	Spring Range
Outside tent/Upstream								
1	0.3	0.2- 0.5	0.5	0.2- 1.5	0.3	0.2- 0.4	0.6	0.2- 0.7
4	1.4	0.4- 2.5	0.7	0.0- 1.4	0.6	0.5-0.7	1.1	0.9- 1.6
7	7.2	4.2- 9.2	0.9	0.8- 2.0	1.0	—	1.2	0.6- 2.4
10	7.7	1.6-14.5	2.7	0.6-11.8	—	—	1.0	0.4- 1.7
Average	4.2	0.2-14.5	1.2	0-11.8	0.6	0.2- 0.7	1.0	0.2- 2.4

Well No.	Code	Nitrogen kg/ha	Nitrogen lbs/acre	Season 1977-1978: Summer Avg.	Summer Range	Fall Avg.	Fall Range	Winter Avg.	Winter Range	Spring Avg.	Spring Range
Inside tent											
2	212A	237	212	2.8	2.0- 4.6	6.8	3.9-12.0	1.8	1.3- 2.2	2.0	1.6- 2.6
3	212A	237	212	5.7	3.9- 7.0	9.5	5.1-17.8	3.9	3.4- 4.8	1.9	1.2- 2.9
5	162B	181	162	19.3	14.0-23.2	24.9	22.8-27.3	25.0	24.6-25.4	22.6	19.2-25.6
6	162B	181	162	13.2	9.5-16.5	19.6	16.4-21.2	13.6	11.7-14.7	10.4	9.8-11.0
8, 9	212A	237	212	18.8	14.0-27.0	25.0	20.7-33.0	24.4	24.0-24.6	23.3	10.5-29.6
11, 12	162B	181	162	18.4	15.0-22.5	16.9	10.0-25.2	17.7	16.8-18.6	21.6	14.8-26.4
Brook				1.4	1.2- 1.8	1.9	1.4- 2.5	4.6	4.4- 4.8	1.9	1.6- 2.0

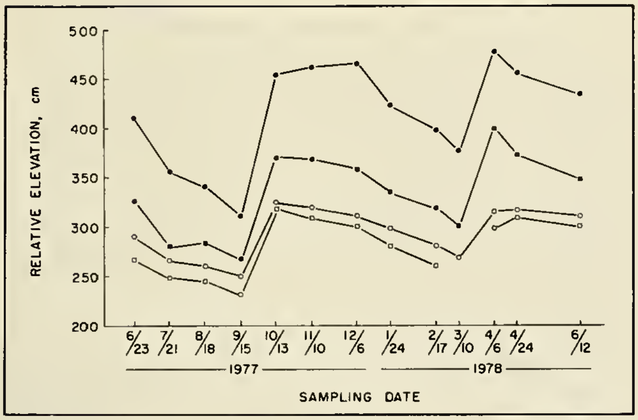

Fig. 5. Relative ground water elevations in the 12 wells changing with time in 1977-78. Merrell Farm, Suffield. Filled circles = average of wells 1-3; filled squares = average of wells 4-7; unfilled circles = average of wells 8 and 9; unfilled squares = average of wells 10-12.

Turf plots. Table 5 shows the observations over 3 years. The water in the small diameter nylon tubing (1 mm I.D.) was usually frozen during the winter. The NO_3-N determinations made on the 240 and 300 cm depth were averaged since no significant differences were measured. The observations of wells 1 and 5 are recorded separately because concentrations in well 5 tended to be higher than those of well 1. Well 5 is within the western-end of an old, for the most part unused, tobacco seedbed area. The soil is still high in organic matter, which could release nitrates by mineralization.

The samplings show generally low NO_3-N concentrations. One observation of 10 mg L^{-1} in Fall 1975 may have resulted from a sudden flux of nitrate from the nearby seedbed area or from the cultivation and fertilization of the soil during the establishment of the turf plots. Otherwise, Table 5 indicates that enrichment of the incoming ground water by the N fertilization of the turf is insignificant with or without the returning of the grass clippings. However, the turf plots are still too young for an evaluation of the long term effects of their management on the NO_3 levels of the ground water.

Merrell Farm, Suffield

The observations covered two growing seasons: 1977, a relatively wet year (1368 mm = 56.86 inch of total precipitation) and 1978, a relatively dry year (926 mm = 36.47 inch). The fluctuations in the levels of the ground water and its general flow direction are illustrated by the once-monthly water levels measured during the first year and summarized in Fig. 5. The measurements generally show a downward gradient from well 1 to 12 of about 180 cm (6 ft), substantiating the general south-east to north-west direction of the ground water flow (Fig. 6). A drastic recharge occurred during heavy rains in September 1977 (208 mm = 8.17 inch) and one slightly less intense during late Spring 1978. During the 1978 season no leaching rains occurred and the ground water level in field 9 gradually dropped, drying up some of the wells. We observed the first rise in ground water levels (about 4.5 cm = 1¾ inch) in early December.

The NO_3-N concentrations in the ground water and brook during the two seasons are summarized in Tables 6, 7, and Fig. 6. The data of the first year (1977-78) as presented in Fig. 6, illustrate the striking differences in NO_3-N concentrations in the ground water sampled under and just outside field 9 (see Fig. 2 for the location of the wells). The concentrations inside the shade tent are generally higher than those outside the tent. Except for wells 2 and 3, the NO_3-N levels inside the tent are usually higher than 10 mg L^{-1}. The relatively low NO_3 concentrations in wells 2 and 3 are apparently due to dilution by uncontaminated ground water from the east and/or by denitrification as discussed later.

The NO_3-N concentrations for both seasons are summarized in Tables 6 and 7. The data of the two wells in each sampled plot were averaged if the differences in these concentrations were small and inconsistent; larger and more consistent differences are reported separately. Significant differences in NO_3-N concentrations may be related to variations in soil conditions. The drainage of the soils around wells 2 and 6 is less than that of the soils around wells 3 and 5, while the whole area is classified as moderately well-drained. Therefore, in these situations a difference in denitrification of the percolating nitrates may have occurred (25). The differences between well 8 and 9, both located in well-drained soils, during the 1978-79 fall season are harder to understand (Table 7). However, during this season with low leaching the incoming flow of uncontaminated ground water from the adjacent brush land may have caused dilution. Local deviations of the south-east to north-west ground water flow are likely. An example of

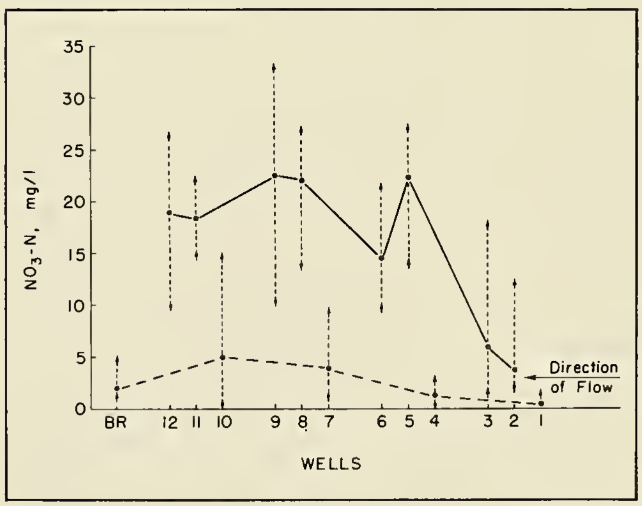

Fig. 6. NO_3-N concentrations — averages, highest, and lowest — in ground water wells and brook as measured on mostly bi-weekly samplings over one year (6/9/77-6/26/78) on the Merrell Farm, Suffield. (Wells inside the tent unbroken line; wells outside the tent broken line.)

Table 7. Summary of NO_3-N concentrations (mg L^{-1}) in the ground water near and under a commercial shade tobacco field, Merrell Farm, Suffield. Season 1978-1979.

				Season 1978-1979					
				Summer		Fall		Winter	
Well				Avg.	Range	Avg.	Range	Avg.	Range
Outside tent (upstream) Average (wells 1, 4, 7, 10)				2.6	0.2- 5.6	2.7	0.2- 8.8	1.3	0.5- 3.0
				Season 1978-1979					
		Nitrogen		Summer		Fall		Winter	
Well	Code	kg/ha	lbs/acre	Avg.	Range	Avg.	Range	Avg.	Range
Inside tent									
2, 3	237A	265	237	2.0	0.5- 3.6	—	— —	1.9	1.2- 3.4
5	187B	209	187	21.5	13.6-26.0	11.8	6.2-20.2	20.8	19.6-23.2
6	187B	209	187	10.9	8.4-13.6	7.2	5.6- 8.8	7.6	6.0- 9.2
8	237A	265	237	25.3	23.2-27.0	23.8	22.0-25.6	25.5	24.0-26.4
9	237A	265	237	22.3	20.0-23.4	8.0	1.4-16.8	23.5	23.2-24.0
11, 12	187B	209	187	20.2	18.6-23.2	18.2	17.4-19.4	18.3	15.2-21.4
Brook				1.9	1.6- 2.1	2.2	1.5- 2.8	2.3	1.0- 4.5

Table 8. Effect of various amounts and programs of fertilization on yield and crop index of shade-grown cigar wrapper tobacco.

Fertilization											
		Nitrogen				Yield[z]				Crop index[y]	
Code		kg/ha		lbs/acre		kg/ha		lbs/acre		$/acre	
1977	1978	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978
162A	187A	181	209	162	187	1393	1571	1244	1403	5970	6787
162B	187B	181	209	162	187	1396	1574	1246	1406	6250	6690
187A	212A	209	237	187	212	1407	1562	1256	1395	6081	7119
187B	212B	209	237	187	212	1445	1571	1290	1403	6584	7458
212A	237A	237	265	212	237	1425	1563	1272	1396	6415	7448
212B	237B	237	265	212	237	1458	1566	1302	1398	6674	7289
L.S.D. (0.05)						N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

[z]Harvest of 6 primings in 1977; 5 primings in 1978.

[y]Sum of products of yield of each priming times its market value.

this can be found in Table 6. The wells outside the shade tent show an increase in the average NO_3-N concentrations toward the downstream side of the field (see also Figs. 2 and 6). This indicates that at least in this area a more westerly or south-westerly flow took place, which brought the nitrates from the shade tent. However, only a few NO_3-N concentrations of over 10 mg L^{-1} were observed during the summer. The heavy rains in September rapidly reduced the NO_3 concentrations to normal for the wells outside the tent.

Furthermore, the data of Tables 6 and 7 show that the effects of the two amounts and programs of fertilization on the NO_3-N concentrations did not differ significantly. In the 1977-78 season, for example, a comparison of the NO_3-N concentrations of wells 8 and 9, and 11 and 12 shows slightly higher concentrations from treatment 212A (wells 8 and 9) than from treatment 162B (wells 11 and 12). On the other hand, treatment 162B as sampled in well 5 shows equally high or higher NO_3-N concentrations than the treatment 212A (wells 8 and 9).

Finally, as shown in Table 8, the various fertilizer treatments in both seasons did not produce any statistically significant differences in yield and crop index. The yield and quality of wrapper tobacco as evaluated by the crop index, showed a slight benefit from the greater amounts of fertilizer and particularly the better distribution due to increasing the number of side-dressings (Table 1) in the 1977 season. These effects are shown consistently in the 1978 harvest. The yield and quality of the five primings in 1978 are significantly higher than those of the six primings in 1977. Although the heavier fertilization rates and the weather conditions undoubtedly played a role, the main reason for these increases in yield and quality were caused by the change in 1978 to a new strain of shade tobacco, better suited for the growing conditions of field 9.

DISCUSSION

An adequate supply of nitrogen is difficult to maintain in leachable, sandy soils. Thus, the production of Connecticut's cigar tobacco is based on the use of several natural organic nitrogenous materials as fertilizer (5). These expensive N sources are mainly used because they resist leaching from rains and irrigation. Other reasons are time, rate, and amount of decomposition, which determine the availability of NO_3 to the plants. Since cigar tobacco is rarely adversely affected by an over-abundance of N (5), there is a tendency toward heavy fertilization to insure against leaching. The amounts of N applied vary from about 200 kg/ha (180 lbs/acre) to about 250 kg/ha (225 lbs/acre), depending on the conditions. Preplanting applications may be supplemented with one or several side-dressings or with liquid fertilizer applications through the irrigation system at 33 kg/ha (30 lbs/acre) to 45 kg/ha (40 lbs/acre) of N.

Since shade tobacco utilizes about 151 kg/ha (135 lbs/acre) of N (2), there is a considerable potential for the accumulation of unused N residue, particularly from the organic sources (16). Other factors can contribute to relatively high organic N levels in soils used for shade tobacco, which can sustain high NO_3 concentrations in percolating water. Unless there is a cover crop, part of the unused N will be lost before the next season by leaching from the soil. In lysimeter studies at the Valley Laboratory (17), a rye or oat cover crop reduced leaching losses of NO_3 by about 50 kg/ha or 45 lbs/acre of N.

Another important factor in increasing organic soil-N levels is that only a fraction of the tobacco plant is harvested; most is returned to the soil. During 1966-1968 the average harvest weighed 1544 kg/ha (1379 lbs/acre), removing 103 kg/ha (92 lbs/acre) of N (2). In recent years, 18-19 leaves are harvested by weekly primings of 2 to 4 leaves, starting at the bottom of the plants. However, the primings from the 3 to 4 m (11 to 13 ft) tall plants may vary from 16 to 22 leaves, depending on the market, weather conditions, and available labor.

The remains of the tobacco and cover crop supply considerable amounts of organic matter for microbial action. Under favorable conditions this may immobilize considerable amounts of N in microbial cell tissue (60-110 kg/ha or 54-98 lbs/acre) (10).

Therefore, it is not surprising that under the shade tent of field 9 on the Merrell Farm ground water contained relatively high concentrations of nitrate (Fig. 6 and Table 6 and 7). As we observed in 1977-79, accumulated soil and residual fertilizer N sustained a year-round, relatively high NO_3–N concentration in the ground water, averaging about 16 to 25 mg L^{-1} under the middle and downstream part of the field.

The amount of water that percolates annually through sandy terrace soils in the Connecticut Valley can be estimated from the average annual stream flow at 10 long-term gaging stations of the United States Geological Survey (24). Assuming that little water moves by overland flow, their data corresponds to an annual "runoff" of about 58.42 cm (23 inches). This means that about 5,842,000 L of water per ha percolate through the soils annually. On field 9 of the Merrell farm an average ground water concentration of 16 to 25 mg L^{-1} NO_3–N amounts to an average loss of N of 93 kg/ha (83 lbs/acre) to 145 kg/ha (129 lbs/acre). It is not difficult to understand that in the light of such losses our relatively small differential fertilizer treatments, 28 to 56 kg N/ha (25-50 lbs/acre), did not produce any significant effect on yield and quality of the tobacco.

The enrichment of the ground water under the farm of the Valley Laboratory was less, reflecting its less intensive cultivation (Table 2). Even the local, transitory enrichment downstream of the old shade tent (OT-Fig. 1) was less pronounced. (Fig. 4 and Table 3). However, shade tobacco had been grown there for only 9 years and its overall management was less intensive than on field 9 on the Merrell Farm. For example, manure was never used. Besides, the area (0.56 ha = 0.5 acre = 20 bents) was relatively small, therefore, dilution by incoming ground water is an important factor. Further, the few wells inside and around the old shade area were not well placed. As illustrated in a previous study (23), the heterogeneous nature of our layered soils, derived from fluvioglacial or outwash materials, creates an unpredictable flow and leaching characteristics along fingers of flow below the 60 cm (2 ft) depth. It will take more and better-located sampling stations to get a reasonable picture of the movement of nitrates in and from the old shade tobacco area (OT-Fig. 1).

The relocation of the shade tent to an area that had not been intensively cultivated on the Valley Laboratory farm offered an opportunity to improve the ground water sampling under shade tobacco (NT-Fig. 1). The results in 1977 show modest contamination with NO_3 (Table 4). Some of the NO_3 may have come from the adjacent old shade tobacco area or from a small area planted to field corn.

The ground water under the turf plots did not show measurable enrichment with NO_3 (Table 5) despite fertilization of 179 kg of N (160 lbs/acre) annually for 3 years. This result agrees with findings elsewhere. In lysimeter studies at Ithaca, NY, small leaching losses of NO_3 were measured under timothy grown on a silty clay loam (3); at Windsor, however, in sandy soil moderate losses were observed when N was applied at relatively high rates (17). In the Netherlands, smaller losses of NO_3–N were found on grassland than under cropland, despite higher N fertilization. The leaching of an average of 3.5 mg L^{-1} on grassland was not affected by soil type, while under cropped arable land an average NO_3–N concentrations of 9.5 and 25 mg L^{-1} were observed, respectively, on fine-textured and sandy soils (12). According to other Dutch studies, many factors are responsible for the small losses of NO_3 from grassland (10,11): the use of fertilizer and manure in several applications during the year; the usual rapid uptake of N by a permanent, almost continuously and vigorously growing grass cover; removal by the immobilization of N by micro-organisms; and by denitrification.

The potential for significant NO_3 leaching was even less on our turf plots since we used a moderate rate of fertilizer (19), containing 50% slow-release organic N sources. However, high rates of water-soluble, inorganic N applied to turf and liberal irrigation can increase leaching of NO_3-N, especially on sandy soils (20).

On cropped, arable land the potential for NO_3 leaching is much greater. The fertilizer is usually applied just before sowing or planting when the N utilization by the crop and also the immobilization by microorganisms are slight. However, under subtropical conditions in Florida, observations did not indicate that agriculture caused any permanent accumulation of NO_3 or other nutrients in the ground water (18). In situations where there is a possibility for appreciable contamination of ground water, corrective measures could be taken: reduce the total N applied; split the amount into frequent, lighter applications, or inhibit nitrification in the soil.

A combination of the first two measures appears to be most practical. On sandy soils in Central Wisconsin, the yield of potatoes was not affected by a decrease of applied fertilizer N from 260 to 170 kg N/ha (232 to 151 lbs/acre) and a decrease in applied irrigation water from 45 to 27 cm (18 to 11 in). However, the yield of grade A tuber was improved when irrigation was applied every 3 rather than 5 days, and fertilizer N was applied in 11 rather than 3 doses (21). On Long Island, potatoes were satisfactorily grown while diminishing the fertilization rate of 224 kg of N/ha (200 lbs/acre) to 162 kg of N/ha (145 lbs/acre), with 1/3 applied at planting time and 2/3 applied as a side-dressing about June 1 (4). Extensive studies of N fertilization of corn in New York (13) indicate that to grow corn continuously on coarse- to medium-textured soils, 112 to 157 kg of N/ha (100-140 lbs/acre) are required, with most applied as summer side-dressing.

A nitrification inhibitor developed since 1962 (6,9) is used to stabilize urea and ammonium N fertilizers on wheat in the Northwestern United States (7). Unfortunately, the technique is not suitable for the production of wrapper tobacco in Connecticut. Premium quality tobacco requires a satisfactory supply of NO_3-N readily available to the tobacco plants. Ammonium-N produces a tobacco that cures to an undesirable dark wrapper (1,5).

Thus, for the tobacco grower in Connecticut, one route to minimizing NO_3 leaching might to be to tailor NO_3-N fertilizer applications to the needs of the tobacco crop. Two year's results at the Merrell Farm indicate that multiple post-planting fertilizer applications did not harm the production of shade-grown wrapper tobacco. The permanent, overhead irrigation system could form a convenient means to meter NO_3-N to the plants. This possibility is now under investigation at the Valley Laboratory.

SUMMARY AND CONCLUSIONS

Ground water under the Valley Laboratory farm averaged 3 mg L^{-1} NO_3-N over 3 years. The experimental farm operations increased the 2.5 mg L^{-1} concentration of the water flowing into the farm to an average concentration of 4 mg L^{-1} NO_3-N leaving the farm. Concentrations of over 10 mg L^{-1} NO_3-N were observed after heavy rainfall. These temporary increases usually occurred in the fall, downstream from areas treated with generous amounts of fertilizer. In the Fall, 1977, the water entering the north-west corner of the farm showed a sudden increase in NO_3-N concentration (up to 18 mg L^{-1}), apparently from an adjacent, upstream residential area.

The ground water under the turf plots was not significantly influenced by moderate fertilization treatments during the 2½ years of observations. These observations suggest that as long as a reasonable N-fertilizer program on lawns is followed, the potential for NO_3-leaching under turf is not significant. However, these studies will continue to detect long-term trends.

On the Merrell Farm in Suffield, in a rural environment with comparable soil conditions, we found a different situation. Long-term effects of fertilizations with predominantly organic materials and intensive shade tobacco management sustained year-round high levels of NO_3-N concentrations in the ground water. The NO_3-N concentrations averaged 20 mg L^{-1}, except in the upstream corner of the field, possibly due to dilution with incoming water with a very low NO_3 concentration and/or by denitrification under the less than well-drained soil conditions in this area. Under these conditions of high soil N levels, decreasing the amount of fertilizer N applied or increasing the number and total amount of post-planting applications did not significantly affect NO_3 leaching.

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